Laser induced fluorescence measurements of ion density distribution on PS-1 device

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Introduction.

Streams of cold plasmas are widely applied in many fields of techniques and technology nowadays (microelectronics, ion sources, plasma propulsion engine (PPE) [1]).Diagnostic of such type of plasma is important for technologic process maintaining, and further evolution of specific technical devices.

Results of radial distribution measurements of Ar II ions concentration in PS-1 device [2]. The PS-1 device is a mirror magnetic trap with a toroidal divertor and a magnetic nozzle. Device is used for developing principals of ECR plasma creation in plasma propulsion engine experiments and ICR plasma heating. Measurements were performed in ECRH region of plasma source part of device. Ar II Concentration was obtained by laser-induced fluorescence (LIF) method, using metastable state laser pump at 611.5 nm and fluorescence registration at 460.9 nm.

Experimental setup. PS-1 is a module device, and some volumes, like gas inlet chamber, may be attached or removed from it. Basically the PS-1 device consists of three vacuum volumes - a source of plasma, ion cyclotron resonance (ICR) heating volume, and receiving chamber. Gas is injected into device directly through the source volume also does microwave power. ECRH may be performed by two antennas, one being positioned along main axis of device and

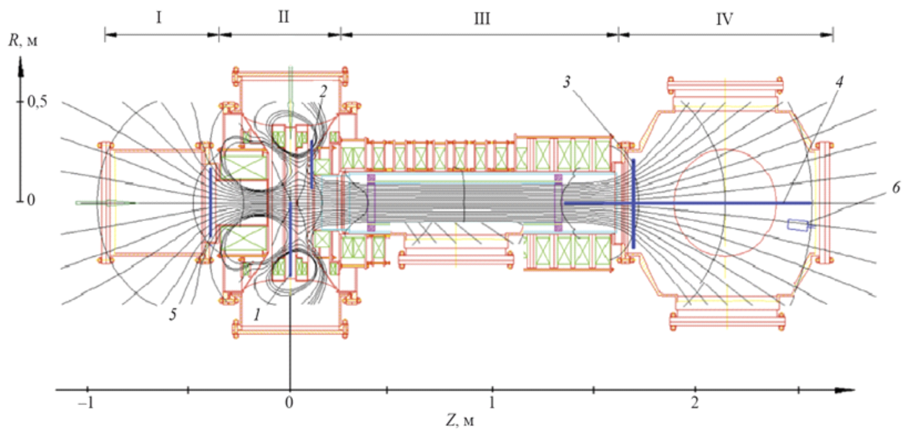

Fig.1. Schematic view of the PS-1. Vacuum volumes of the device: I—gas volume ; II—ECR heating; III— ICR heating; IV— receiving volume; *1*, *2*— Langmuir probes; *3*, *4*, *5* — rows of probes; *6* — grid analyzer.

Table 1. The basic parameters of the PS-1 device:

Length of the vacuum chamber, m	3.75
Separatrix diameter in the plasma, m	0.35
Maximum diameter of plasma, m	0.15
Magnetic field in center, T	0.25
Freq. of ECR generator, GHz	7
Highest input microwave power, kW	20

other perpendicular to it. Helical antenna is placed in the ion heating volume, the configuration of magnetic field with "magnetic nozzle" configuration

with diverging field lines is implemented in the receiving chamber. Gas pump out is performed in the receiving chamber along with plasma particles energy analyzers. The ICR heating was not used in the present experiments, and the solenoid was simply a long mirror trap with mirror ratio ~3.

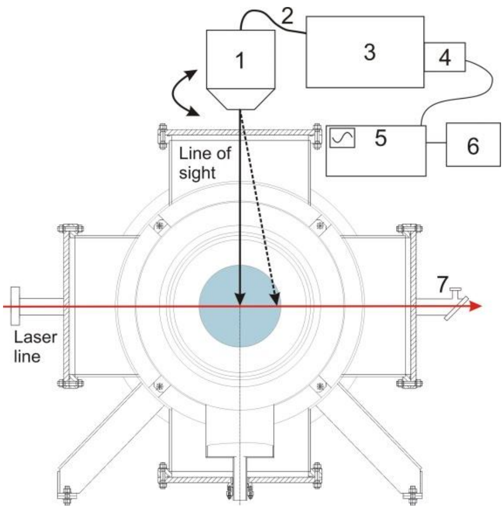

Fig.2. Layout of diagnostic:1-scanning module, 2-optical fiber, 3- monochromator, 4-PMT, 5-oscilloscope, 6-PC, 7-window with Brewster's angle

Diagnostic equipment. Laser beam is generated by tunable optical-parametric oscillator (OPO) ESTLA NT342A-SH-20-AW pumped by the third harmonic of the Nd:YAG laser at frequency 20 Hz. Laser spectral width is 5 $cm^{-1}$and suits the density measurements. OPO is tuned from 210 to 2100 nm. Maximum laser energy is attained at 450 nm wavelength and amount to 15 mJ. Laser beam is guided through device across transverse section between divertor coils. Device is equipped with output window with Brewster's angle used to decrease stray light for LIF measurements and calibration. Mechanical scanning module consists of a 175 mm focal length, 56 mm-diameter lens that collects the emitted fluorescence radiation from different points in plasma, and images it to the edge of the optical fiber. The observation length is 32 mm on the laser beam path and can be changed to improve special resolution. Collected light is sent by optical fiber to the monochromator MDR-23 slit. Monochromator is used as a tunable optical filter. Radiation is collected by the PMT Hamamatsu R-562. The PMT signal is registered by oscilloscope Tektronix-3032, connected to PC, with low-frequency fluctuation cutoff filter. Fluorescence light was gathered and registered in "magnetic nozzle" by the same apparatus, except Hamamatsu H11526-110-NF PMT was used and there was no scanning module, only collecting optics.

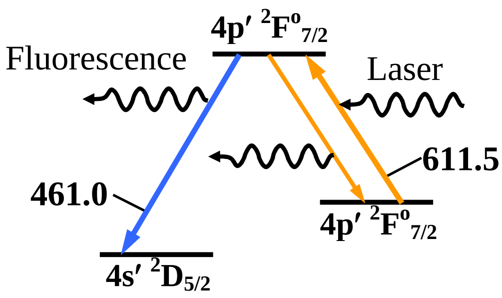

Fig.3. Applied fluorescence scheme.

Collision-radiative model. Collision-radiative model (CRM) [3] is used for interpretation of LIF signals. According to modeled fluorescence scheme, the excitation is produced from metastable state *3d* $^2G_{9/2}$ to state *4p* $^2F_{7/2}$ on the wavelength λ_{LASER} = 611.5 nm, and fluorescent signal is registered at λ_{FLU} = 461 nm (transition *4p* $^2F_{7/2}$-*4s* $^2D_{5/2}$). The model considers 6 levels of Ar II ion. The number of used atomic levels could be increased, but due to lack of information about excitation cross-sections and lifetime of argon atomic states it is a difficult task. Alongside with LIF measurements we perform emission spectroscopy measurements for verification of the LIF scheme via observing the bright lines of Ar II. Alternative fluorescence scheme λ_{LASER} = 440.1 nm (3d $^4D_{7/2}$ - 4p $^4P_{5/2}$) λ_{FLU} = 480.6 nm (4p $^4P_{5/2}$ - 4s $^4P_{5/2}$) was applied with the view to examine the possibility of using different schemes. CRM for this scheme was created by our team using data about excitation rates from ground state of Ar II from work [4]. The main difficulty in developing CRM models for argon ion Ar II is the lack of information about excitation rate coefficients for different levels.

Absolut calibration of diagnostic apparatus were performed by Riley scattering on air and argon. The LIF pump laser was used as a light source for scattering. Laser has inner energy meter so it allows us to correlate laser power (number of photons) with detected PMT signal

Results. Results are obtained in the following device operation mode: gas pressure P=1 *10^{-4} Torr, coils current I_k=1.2kA, injected ECR power W=5kW, discharge duration T=1s. ECR heating power is coupled into the device along transverse section in ECR heating volume. LIF signal was gathered from 50 ms to 250 ms of discharge. Device works in two submodes: with additional gas feeding (pressure in the chamber for the pulse duration is increased twice) and without additional gas feeding. The CRM requires input data on plasma parameters, electron density n_e and temperature T_e, received from Langmuir probe measurements performed in the same transection.

Integral relative fluorescence intensity correlates with electron temperature (Fig.5) due to mechanism of initial populating of the metastable level. Population of metastable state $3s^2 3p^4 (^1D) 3d^2 G_{9/2}$ does not depend on electron density up to values of 10^{13} cm^{-3} according to modelling results. Relative integral intensity was obtained by summing area under the LIF signal.

Thus, the CRM and calibration allow obtaining the absolute values of argon ion Ar II density across plasma radius (Fig.6). Signal ratio of two LIF scheme was used to get queletative information about electron temperature. Due to different energy levels of used metastable states LIF signal will be different and will correlate with temperature Te.

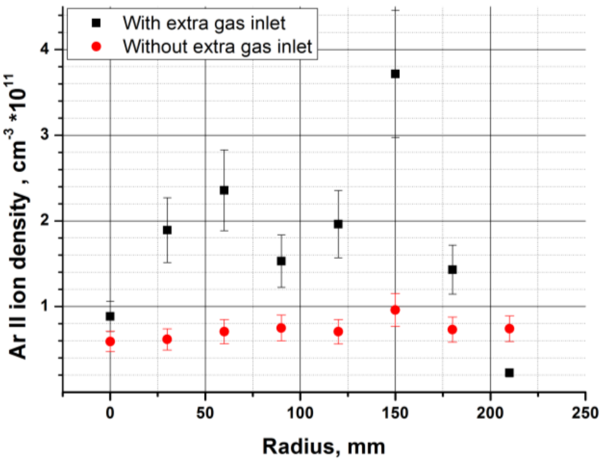

Fig.4. Argon ion Ar II density's radial distribution.

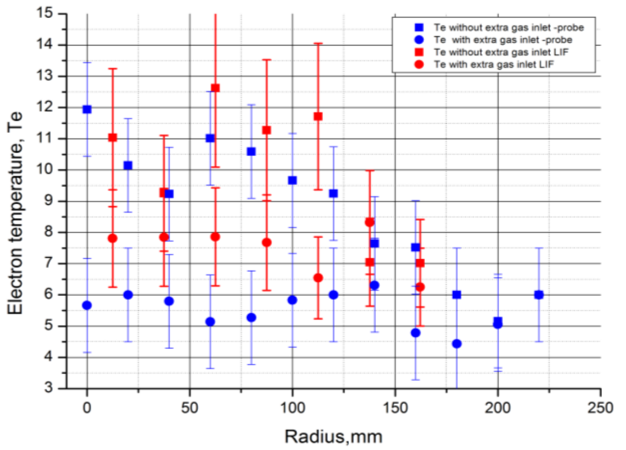

Fig.5. Radial electron temperature distribution

Summary and future plans. Results of using the OPO for LIF measurements of Ar II on the PS-1 device are presented. Application of different LIF schemes is used for electron temperature analyze.

Acknowledgement. This work was carried out with the help of the PS-1 team.

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